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FAILURE ANALYSIS OF A 100-kW WASTE HEAT RECOVERY HEAT PUMP

C.E. Keyes

Late in 1986, Ontario Hydro acquired a used 100-kW heat pump. The objective of this project was to determine why this particular machine had such a poor service record. This report summarizes the results of the failure analysis. The conclusion was that the particular application rather than the equipment was responsible for the heat pump's poor performance. Site monitoring prior to specifying a heat pump is recommended.

Introduction

Late in 1986, Ontario Hydro acquired a used 100-kW heat pump (Figure 1). This centrifugal, R-114 liquid-to-liquid machine had a poor service record. It is believed that a change in plant operating procedures eliminated much of the waste heat needed to operate the heat pump. The problems of this application were well known to industry and were therefore regarded as a barrier to acceptance of heat pumps for industrial process waste heat recovery.

In 1982, the heat pump was installed in an edible oil processing plant to recover heat from the plant cooling water to heat boiler feedwater make-up (Figure 2). The plant cooling water is circulated to remove heat from batch, semi-batch and continuous processes. A cooling tower completes the circuit, removing excess waste heat not recovered by the heat exchanger and heat pump.

A small amount of oil from the processes is entrained in the cooling water. In anticipation that the heat pump evaporator tubes would become fouled through an oily film build-up, an on-line cleaning system was installed. It consisted of small captive nylon brushes which were shot back and forth through the evaporator by reversing the flow of water through the tubes as required.

Changes in production levels and plant operating procedures resulted in source water conditions falling below minimum design both in terms of flow and temperature. As well, the batch nature of many of the processes resulted in widely fluctuating flows and temperatures which the heat pump had difficulty tracking. Frequent automatic shut-down of the equipment occurred.

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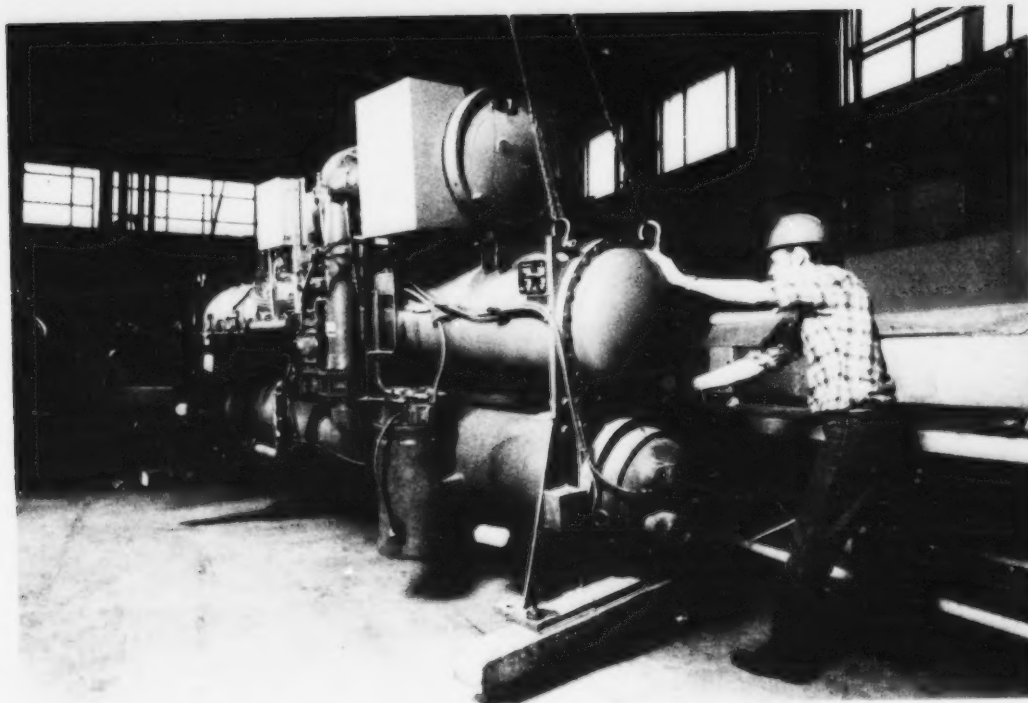


FIGURE 1
100 kW LIQUID-TO-LIQUID HEAT PUMP

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177055-RD
Bart 2 Disk

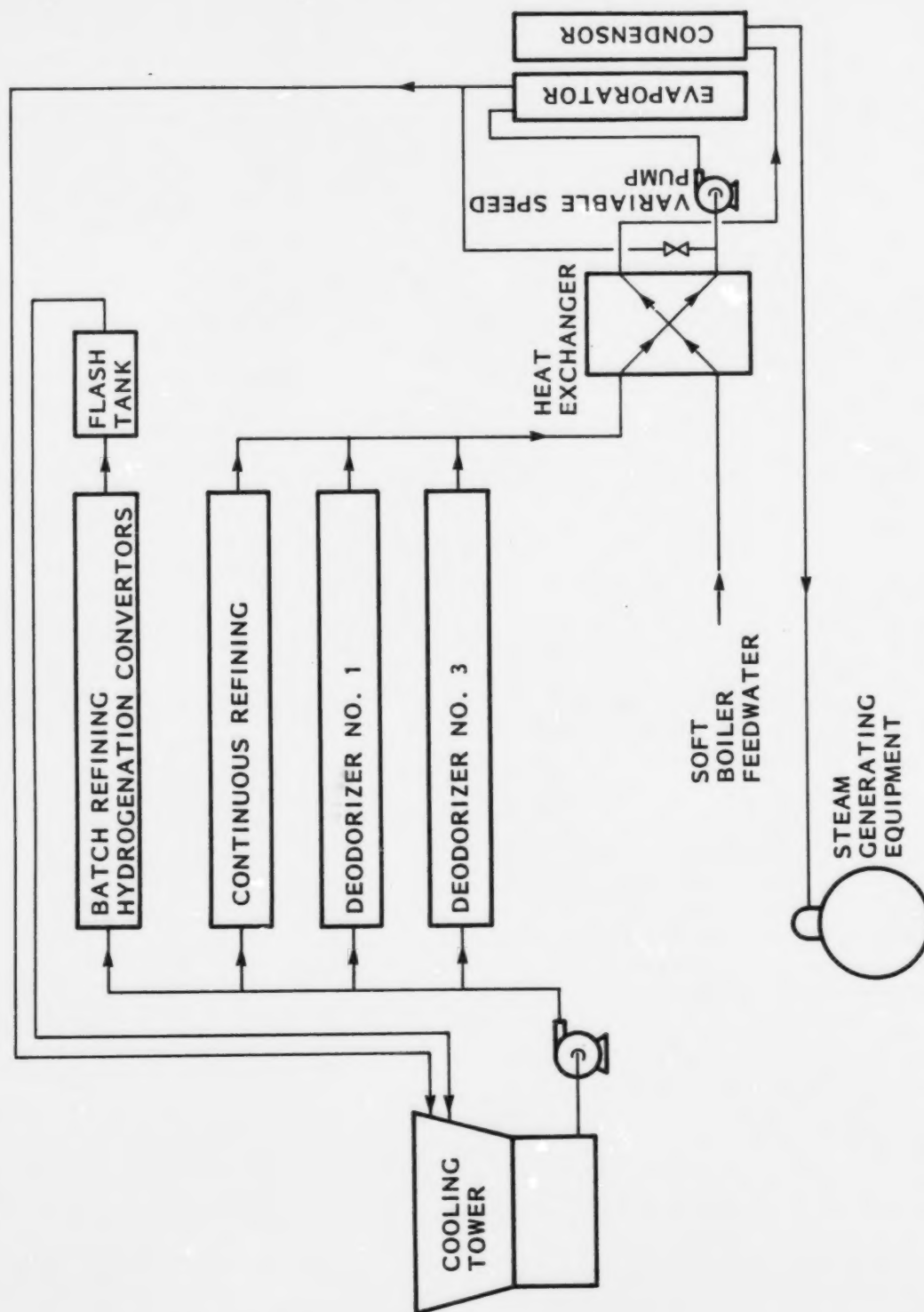


FIGURE 2
ORIGINAL HEAT PUMP APPLICATION*

*Reference 1

A number of other difficulties were encountered which also contributed to its poor service record. The documented problems (Ref. 1) include:

- failure of the compressor motor
- lubricating oil in the refrigerant
- faulty cleaning system temperature sensor
- improper setting of overload relays
- anticycle relay problems (shut down heat pump six times in one hour)
- phase unbalance in the compressor motor

After one year of operation, most of the hardware problems appeared to have been resolved. However, the previously mentioned deterioration of source water temperature and flow led to less frequent use of the heat pump. When the heat pump was sold to Ontario Hydro in 1986, it had logged a total of about 6,000 hours (less than one year's normal service of 8,000 hours). The owner believed the heat pump was still operational provided new temperature sensors were installed in the motor winding protection circuit.

The primary objective of the project was to determine the cause of the poor performance and recommend ways of preventing a recurrence.

Examination of the Heat Pump at Ontario Hydro

Early in 1987, Ontario Hydro contracted an engineering service company with factory trained staff to assist in the examination of the heat pump.

The damage to the heat pump was far more significant than originally anticipated. Inspection of the evaporator tubes revealed extensive fouling with a fatty substance (Figure 3). Many of the small brushes used in the on-line cleaning system were lodged in the evaporator tubes.

Other problems discovered during inspection of the unit included:

- acid in the R-114 refrigerant
- motor stator winding insulation deterioration (Figure 4)
- leaking compressor seals
- oil in the condenser and evaporator
- pitting of the compressor bearings
- copper plate-out on compressor bearing surfaces
- motor temperature sensor burned out
- untrue rotation of the compressor
- thin condenser tubes (up to 75% corrosion)
- broken hot gas by-pass temperature sensor

Complete restoration of the heat pump would require:

- cleaning of evaporator tubes to remove fatty build-up
- rewinding the star-delta motor stator
- replacement of compressor bearings and seals
- retubing the condenser
- charging the heat pump with 400 kg of R-114 refrigerant

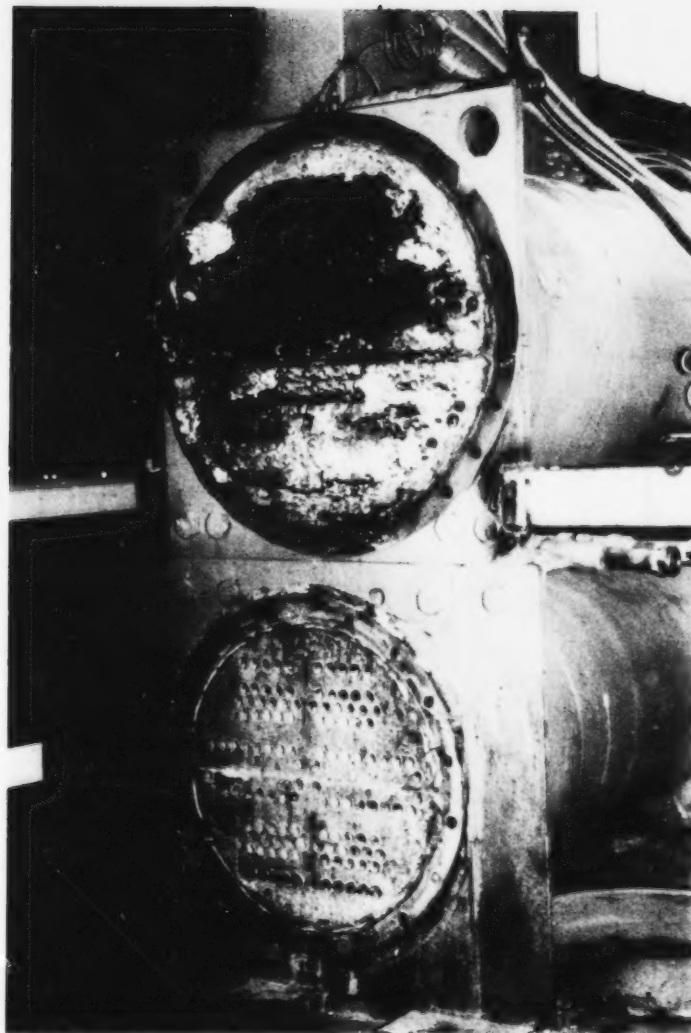
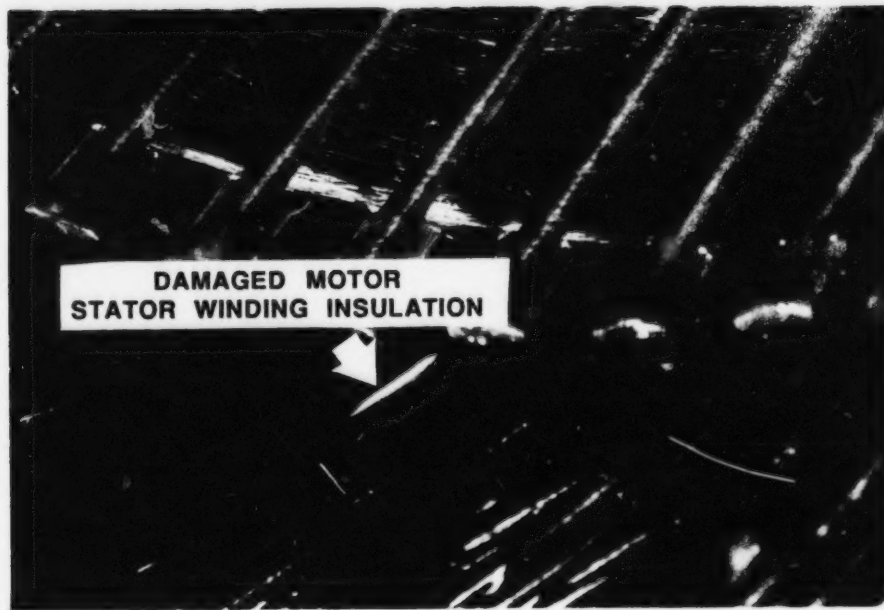


FIGURE 3
FOULED EVAPORATOR (TOP)



**DAMAGED MOTOR
STATOR WINDING INSULATION**

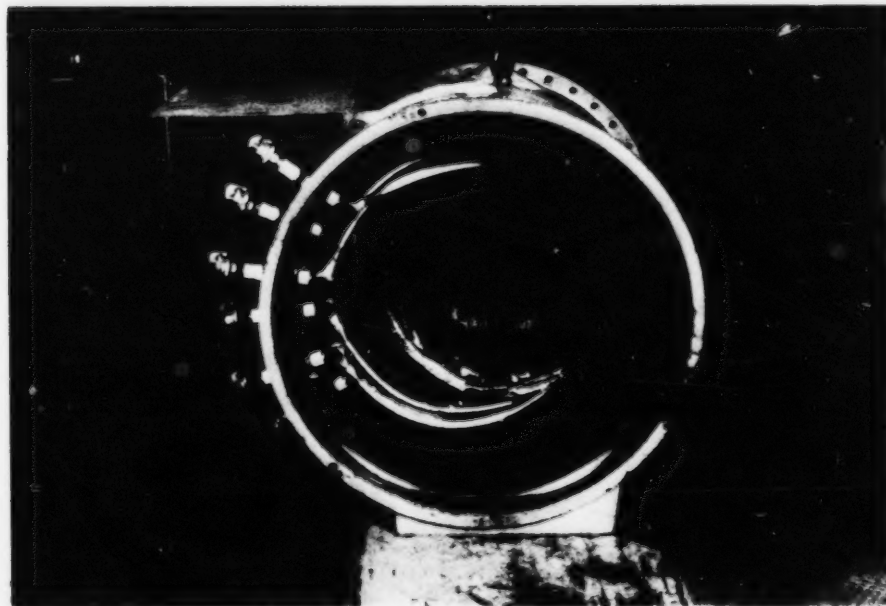


FIGURE 4
COMPRESSOR MOTOR STATOR

The estimated cost of the repairs plus the purchase price of the heat pump exceeded the cost of a new heat pump with similar specifications.

Analysis of Problems

Many of the problems experienced with this heat pump are interrelated. Based on discussions with the engineering firm contracted to assist in the repairs, the four major problem sources were identified as:

- dirty evaporator tubes
- rapid load fluctuations
- moisture in the system
- high pH (alkaline) condenser process water

Figure 5 illustrates the cause and effect relationship between the various failure mechanisms.

The combination of a very dirty evaporator, rapid load fluctuations and moisture in the system is believed to be the main cause of the motor stator winding deterioration, acidity in the refrigerant, motor temperature sensor failure, seal and gasket deterioration and bearing wear. In addition, the alkaline nature of the boiler feed water corroded the copper condenser tubes.

Less heat is transferred across a dirty evaporator resulting in reduced boiling in the evaporator and higher superheat to the compressor inlet. The superheat at the compressor outlet is magnified resulting in a hotter compressor and motor stator.

Rapid load fluctuations, due to unstable source water conditions, plus seal and gasket deterioration increased the amount of oil in the system. (The refrigerant sample analyzed contained 31% oil residue, whereas the amount measured should have been no more than 5%.) The resultant frothy oil/refrigerant mixture had a lower cooling capacity which led to increased motor winding temperatures.

Moisture in the system combined with an elevated refrigerant temperature leads to the formation of dilute hydrochloric or hydrofluoric acids. (Lab analysis of a sample of the refrigerant revealed 7.33 ppm acid and 21.9 ppm moisture. The normal maximum is 2 ppm acid.) Acidity in the refrigerant combined with increased motor winding and compressor temperatures led to:

- copper plate-out on the compressor bearing surfaces (which could have eventually led to seizing)
- motor winding deterioration
- motor temperature sensor burn out
- seal and gasket deterioration
- bearing wear

Bearing wear can be lessened if, prior to start-up, the oil reservoir is heated to drive off the refrigerant it has absorbed. This ensures the oil will have the correct lubricating properties. Improved controls can do this automatically.

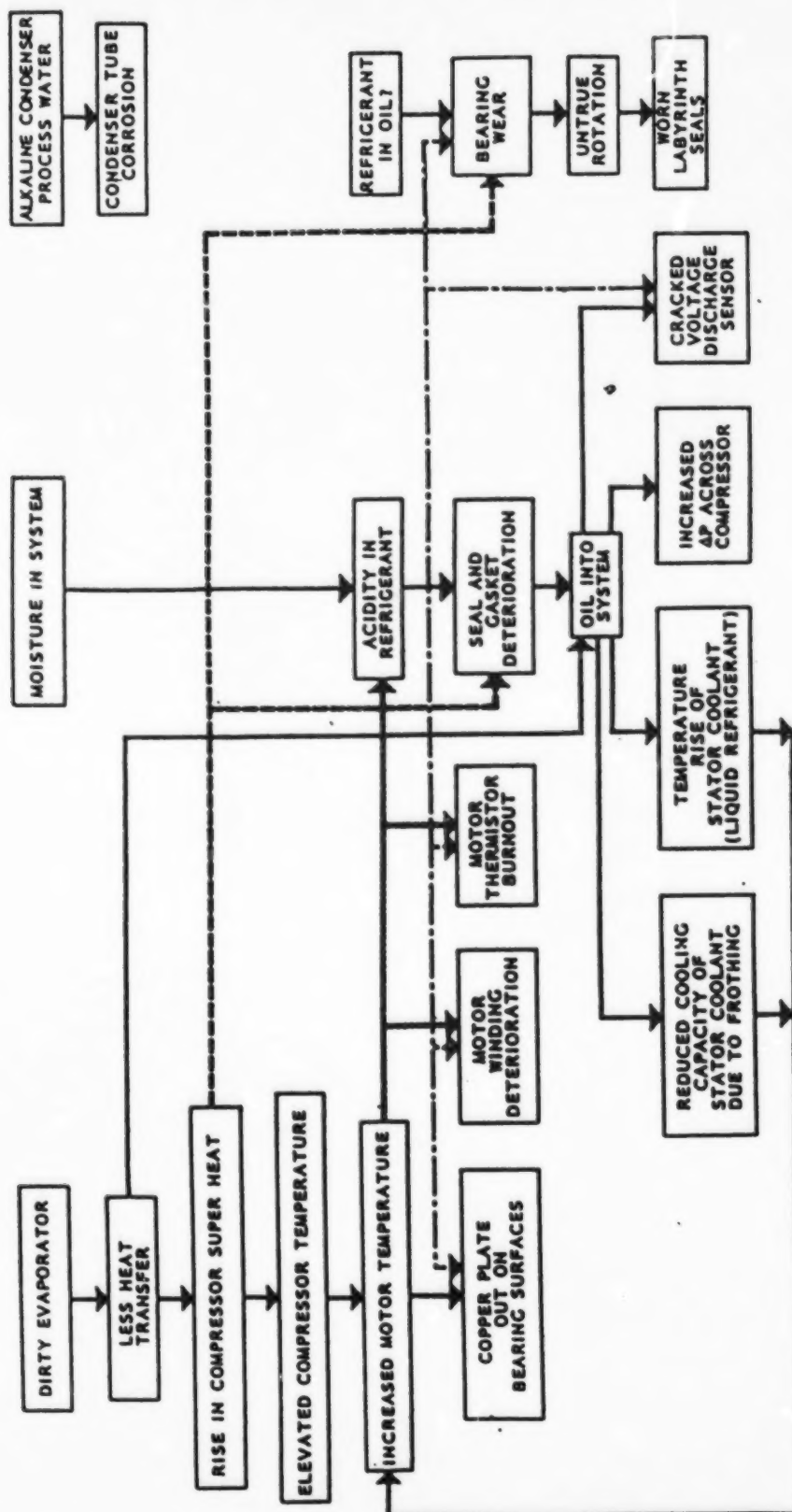


FIGURE 5
ANALYSIS OF HEAT PUMP PROBLEMS

Manufacturers of industrial heat pumps have, in the past, designed heat pump controls similar to that found on commercial chillers; a product they are more familiar with. These controls are adequate for chillers which typically run at fairly constant loads which vary little with time. They are equally satisfactory for heat pump applications with similar properties.

However, many waste heat recovery opportunities do not fall into this category. Temperatures and flows of the source and sink fluids tend to fluctuate widely, presenting too great a challenge for these controls to handle. Nuisance tripping of the heat pump occurs often as a result thereby requiring frequent operator intervention.

Some manufacturers have replaced their electro-mechanical heat pump controls (timers, relays, etc.) with electronic versions. However, in many instances, this was merely a cost saving conversion with no real improvement in performance.

Improved heat pump controls are needed that respond quickly to changes in operating conditions. Such controls would ensure reliable heat pump operation with a minimum of down time and operator attention. If this can be achieved, heat pumps for waste heat recovery may then be considered as a viable technology for a wider range of applications.

Circuits which protect a heat pump from high temperatures or pressures should not be bypassed if they have failed. The heat pump should not be operated until these circuits have been restored.

Table 1 lists the problems, most likely causes, and ways such problems could have been prevented. Although this table is in reference to a specific case, one could take this information into account when specifying a waste heat recovery heat pump.

Recommendations

Heat pump distributors should ensure that the heat pump they supply is both suitable and correctly sized for the customer's application. Site monitoring, prior to ordering, would be helpful in this regard. Particular attention should be given to the properties of the source and sink liquids. Controls should be developed to minimize operator involvement since most heat pump installations are viewed as auxiliary systems. Education on the proper operation and maintenance of heat pumps should be included as part of the heat pump package.

Table 1

PREVENTION OF PROBLEMS

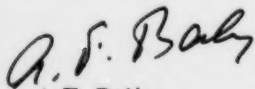
<u>PROBLEM</u>	<u>CAUSE</u>	<u>PREVENTION</u>
Poor heat transfer	-dirty evaporator	improve water quality or use alternate heat exchanger ie. plate or falling film type and clean as required
	-oil in system	check refrigerant for oil/moisture contamination and thermal breakdown
Motor winding failure	-high winding temperature	check refrigerant for excessive oil content
		maintain evaporator heat transfer (reduce fouling)
Copper plateout on bearings	-elevated compressor temp./ acidity in refrigerant	maintain evaporator heat transfer (reduce fouling)
		check refrigerant periodically for acidity
Bearing wear	-elevated compressor temp./ acidity in refrigerant	maintain evaporator heat transfer (reduce fouling)
		check refrigerant periodically for acidity
Seal and gasket deter.	-rapid load fluctuations	ensure source and sink conditions are stable (for centrifugal compressors)
Condenser tube corrosion	-alkaline condenser process water	ensure ph of process water is correct for heat exchange tubes selected.... for copper, the water should be slightly acidic
Frequent tripping of HP	-compressor and controls not matched to application	proper heat pump selection
		improved controls to track HP load

Conclusion

This heat pump presented a rare opportunity to analyze a machine of its size, to document the causes of failure and to recommend preventative measures.

We firmly believe waste heat recovery using heat pumps is a viable technology. However, serious attention to installation detail is required. Failure to do so can lead to unsatisfactory results.

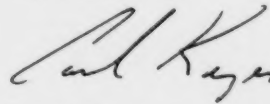
Approved by:



A.F. Baljet
Manager
Electrical Research Dept.

CEK:djb

Submitted by:



 C.E. Keyes
Utilization Engineer
Utilization Section



Reference

1. Gazzola, F.J., "The Monitoring of a Templifier Heat Pump", NRCC Report No25259, February, 1984.

Appendix

HEAT PUMP DESIGN SPECIFICATION

DESCRIPTION	DESIGN
Evaporator water flow (l/s)	31.5
Evaporator temp. in (C)	46.1
Evaporator temp. out (C)	42.6
Evaporator temp. diff. (C)	3.5
Condenser temp. out (C)	71.1
Condenser temp. in (C)	48.9
Condenser temp. diff. (C)	22.2
Compressor (V)	575
Compressor (A)	113.5
Compressor (kW)	101.7
Compressor Motor (RPM)	3450
Estimated Refrig. Charge R-114 (kg)	382